**Atomic Orbitals**

**Presented by: François Bourré and Madgelyn Thompson**

**Overview of the Concept**

**Introduction:**

We start with a demonstrtation of a colorless solution burning with a brightly-coloured flame. The explanation is that the colour of the flame comes from the electrons jumping from a higher orbital to a lower orbital and emitting discrete photons of light energy in the process.

**Background:**

In the early 1900’s, Rutherford-Bohr developed the atomic model (or planetary model) that describes the structure and composition of atoms. This model is first taught to students in the grade 9 science curriculum, and then reviewed again in grades 10 and 11.

Preceding this lesson, students will have learned that Bohr performed spectral analysis (examination of frequency bands emitted) and he used the hydrogen atom to model the amount of energy given off by excited electrons as they changed orbits. Bohr’s hydrogen model was successful and he was able to accurately predict the amount of energy released when excited electrons returned to their ground state.

Unfortunately, Bohr’s energy calculations only worked for the hydrogen atom. When he tried to apply the same calculations to other atoms, the predicted and actual outcomes did not match.

The following video clip summarizes this concept.

Title: Structure of the Atom 4: The Bohr Model

<http://www.youtube.com/watch?v=R7OKPaKr5QM&feature=related>

This 9-minute video is a very clear introduction to the concept of electron configuration, atomic orbitals and energy levels.

We will be focusing on the following basic concept (C3.2) which covers:

Electron configurations, shells and subshells; Pauli exclusion principle, Hund’s rule,

Aufbau principle

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| **Lesson Sequence** | |
| **Lesson Number** | **Specific Goals** |
| 1 | Review previously taught Bohr hydrogen model and view the YouTube video referenced in the introduction |
| 2 | Introduce the concept of subshells (s,p,d,f) and the quantum model of atomic orbitals (n,l,m,s). Show the arrangement of the periodic table based on these subshells. Make the connection between the quantum model and short-comings of Bohr’s model |
| 3 | Demonstration – spectral analysis by flame chemistry. Details are shown below. |
| 4 | Pauli exclusion principal – review quantum numbers with students, shape and configuration of orbitals and ‘n’ equations |
| 5 | Review Hund’s rule as well as the Aufbau principal for mapping shells and subshells |
| 6 | Formative assessment (this is only one of many formative assessments to be used for the entire unit) |

**Theoretical Overview**

**Aufbau Principle:** “aufbau” is German for ”building up”; each electron is added to the **lowest orbital** available in an atom or ion.

**Hund’s Rule:** One electron occupies **each** of several orbitals at the same energy before a second electron can occupy the same orbital.

**Pauli Exclusion Principle**: No two electrons in an atom can occupy the same four quantum numbers; no two electrons in the same atomic orbit can have the same spin; only two electrons with opposite spins can occupy the same orbital.

In anticipation of the misconceptions and difficulties that some students will have, the teacher could follow the suggestions tabled below.

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| **Potential Difficulties / Suggestions** | |
| **Difficulty** | **Suggestion** |
| The planetary model has been taught for the three preceding school years. For some students, the idea of subshells will present a major concept shift. | The idea of subshells must be clearly understood before proceeding with the other lessons. Making the link to Bohr’s work and spectral analysis is key to building upon the quantum model. |
| Some students may not be able to visualize what Bohr did and his work on spectral analysis. | Perform a flame chemistry demonstration/lab to show the different emission spectral bands of light seen using a spectrometer |
| Students may have difficulty visualizing the s,p,d,f orbitals and their placement within the periodic table | Give the students a ‘blank’ periodic table. A useful group exercise would be to ‘fill’ in the first three periods of the periodic table and label each type of orbital as per the quantum model. Diagnostics should be used to ensure comprehension. |
| Some students may have difficulty grasping that two electrons cannot have the same quantum number (n,l,m,s) i.e. Pauli exclusion principal | Assign students to teams and have them work out the quantum numbers for the first two periods of the periodic table. Students can then be selected to present their findings to the class. |

**Advance Preparation:**

Ensure that every student has access to a light spectrometer.

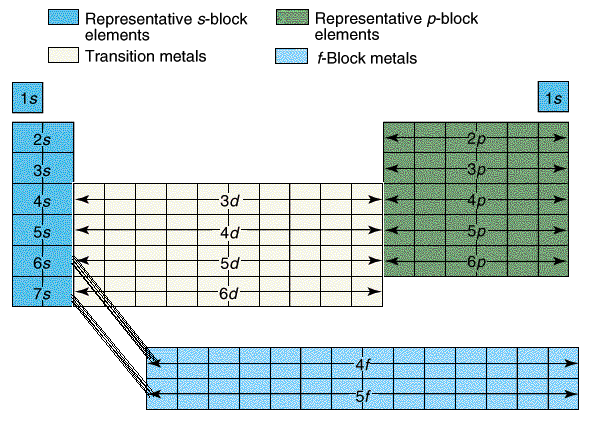
Prepare summative and formative assessment

**Special Materials:**

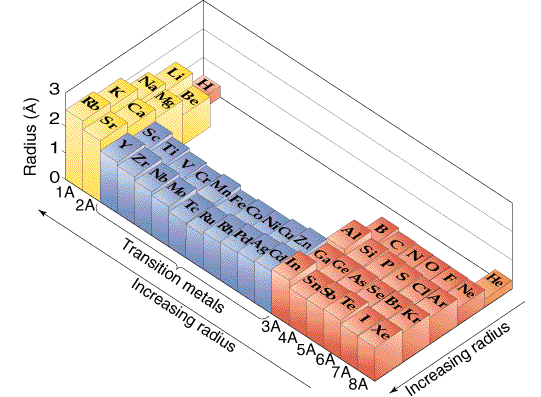
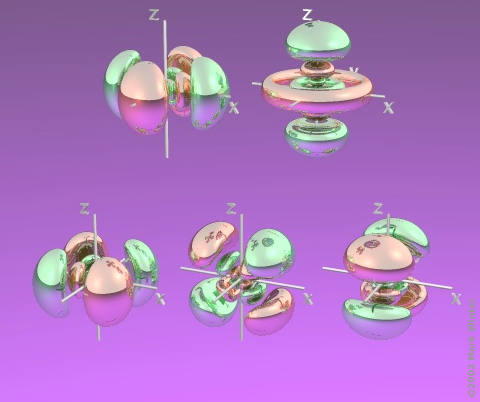
Periodic table, videos, graphs, online simulations, formative assessment (quiz), modelling clay of various colours

**For Flame Chemistry Demonstration:**

Light spectrometer, Bunsen burner, spatula, solution of metallic salt or powdered element, element emissions table

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Abstracted version of the period table, highlighting the subshells. The periodic table used by the student is far more detailed.



3-D image of orbitals.

**Teaching/Learning Strategies**

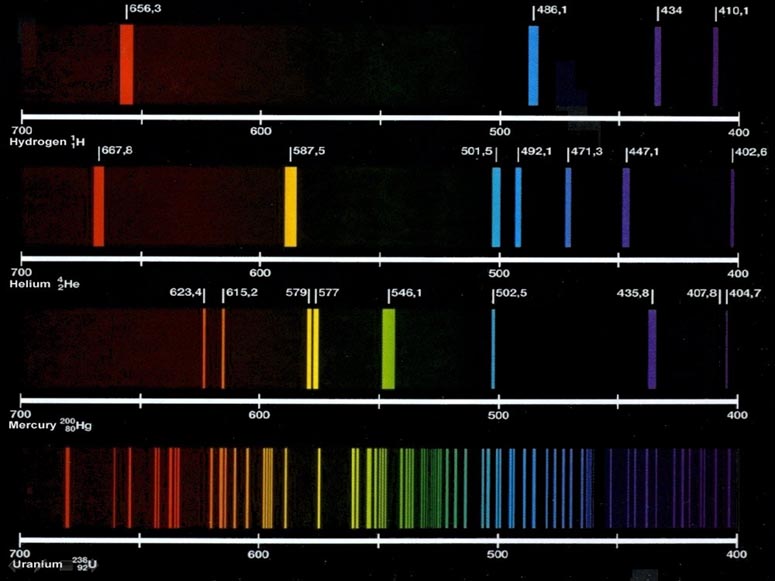
Questions for diagnostic assessment, online quiz for formative assessment with immediate response,

**Visual Aids:** Periodic table, 3-D model of quantum orbitals, videos, demonstrations, online simulations, graphs, model of the atom showing energy levels

**Lab Activity – Flame Chemistry**



In the demonstration portion, students will be given light Spectrometers (left). These units are used to view emission spectra of light. Each element has its own unique ‘signature’ similar to human finger prints; each element emits specific bands of light (see example emission figure below) – ref: 7



In the lab demonstration, we will need a Bunsen Burner and prepared solutions of metal salts or elements (e.g.: CuCl2). We take a small amount of the solution onto the tip of an insulated spatula. We then insert the tip of the spatula into the flame. Using the spectrometer, students will see the corresponding light spectrum. We can further the demonstration by asking students to identify an unknown sample based on an element emissions table.

**Safety Considerations**

Apart from the demonstration mentioned previously, the study of quantum models is very theoretical, so there aren’t many safety requirements:

For the demonstration, students are expected to wear safety glasses and lab aprons. The demonstrator must wear goggles, latex gloves and an apron (or lab coat). The demonstrator must ensure he is using an insulated instrument to insert into the flame. Additionally, the spatula should not be left in the flame for more than 10 or 15 seconds at a time.

**Assessment/Evaluation Tools**

**Assessment for Learning:** Informal diagnostic assessment with question-and-answer format

**Assessment as Learning:**

* Formative assessment using the online quiz before and after the main section of the concept is taught. For each question, the quiz gives the correct answer and critiques the incorrect answer
* Anecdotal notes on student practice and comprehension during the flame using the light spectroscope
* Lab report on the experiment to identify the element through the flame chemistry demonstration and test: this test all four categories

**Assessment of Learning:** Paper-and-pencil unit test at the very end of the unit of which this concept is only a part.

These assessment and evaluation tools are applied to each lesson as follows:

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| **Concept Evaluation** | |
| Lesson 1 | In lesson 1, we will be performing diagnostics to assess if students have firmly grasped Bohr’s work on the hydrogen atom. Ask questions about specific elements in the periodic table, the charge of their ions, the relative ease with which they form bonds etc. |
| Lesson 2 | Students will work in small groups to identify the quantum states of the first two rows on the periodic table. This work will be assessed on a diagnostic basis. |
| Lesson 3 | During the demonstration, students will be asked a series of questions pertaining to Bohr’s work and emission spectrums. The class will be divided into 4 groups and asked to identify an unknown metal salt based on its light band emissions using the spectrometer. |
| Lesson 4 | Students will be asked to take the online quiz for self-evaluation:  <http://wps.prenhall.com/esm_hillpetrucci_genchem_4/16/4218/1079857.cw/content/index.html>. Teams of two will hand in the result of the quiz via e-mail, with score displayed. This will count as a formative assessment. |
| Lesson 5 | There will be a one hour pen and paper formative assessment. Since atomic orbitals are a part of a larger set of concepts, the formatives will prepare students for a final summative assessment which will come later in the unit. |

**Applications and Societal Implications**

The study of atomic orbitals and the development of the quantum model have had far reaching societal and practical implications. Not surprisingly, most people are not aware of its importance and hence they associate atomic orbitals with non-practical theoretical constructs. Practical applications that have arisen from the study of atomic orbitals and quantum mechanics are:

1. The laser
2. Transistors (and subsequently the micro-chip)
3. Electron microscope
4. Magnetic resonance imaging
5. Semiconductors (which are used in most electronics)

Furthermore, the study of atomic orbitals has spawned new fields of scientific research like

spectroscopy, quantum mechanics and seeking a grand unified theory to explain all of the forces

in the Universe (ref: 8).

**Your turn !**

We invite you to view the following videos and then take the ‘quantum quiz’ to test your knowledge on atomic orbitals.

* Theory of Bohr`s model of the atoms: Structure of the Atom 4: The Bohr Model  
  <http://www.youtube.com/watch?v=R7OKPaKr5QM&feature=related>
* Explanation of Orbitals: The Atomic Hotel  
  <http://www.youtube.com/watch?v=cM7vW2AIItM>
* Quantum Quiz: Self-Quiz-Chapter 8 Electronic Configurations, Atomic Properties, and the Periodic Table. Prentice-Hall  
  <http://wps.prenhall.com/esm_hillpetrucci_genchem_4/16/4218/1079857.cw/content/index.html>

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